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HEAT TRANSFER ANALYSIS AND WATER QUALITY IN SALINE WATER DESALINATION USING SOLAR ENERGY IN VACUUM CONDITION

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ABSTRACT

The continues deficiency of consumable water is a significant issue in developing countries, and contaminated water can result in various diseases, which are often lethal. Solar desalination seems to be a promising method and alternative way for supplying fresh water. **Aim:** The aim of this research is to study heat transfer in desalination system and the quality of feed water, distilled water and brine compared to the quality standard. Feed water consists of salinity 12‰ and 38‰ salinity. **Methodology and Results:** At first, initial characterization of feed water was conducted, then temperature on fourteen points was measured using thermocouples and thermometer so heat transfer rate can be calculated. After that, the final characterization of water production was conducted. From the observation, it was found that evaporative heat transfer for vacuum pressure of -0.05, -0.1, -0.15, -0.2, -0.25, and -0.3 bar respectively were 173.77, 180.07, 190.79, 481.66, 242.57, and 246.24 W/m2. The result of water quality test of distilled water produced from saline water desalination for some parameters respectively were pH 7.4; turbidity 2.73 NTU; TDS 27.45 mg/L; chloride 84.98 mg/L; Fe 2.13 mg/L; total hardness 0.1698 mg/L; and *Escherichia coli* 12 cell/mL . **Conclusion, significance and impact study**: It can be concluded that distilled water produced by desalination system was met drinking water quality standard according to Minister of Health Regulation No. 492 of 2010.

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- Desalination
- Heat Transfer
- Saline Water
- Vacuum
- Water Quality

1. INTRODUCTION

Three quarters of the earth surface consists of water, while 97.5% of the water on the earth surface is sea water with TDS higher than 35,000 ppm. In the 2.5% of the total fresh water, only 30% is suitable for use because the majority of 69% fresh water is frozen in the icecaps and glaciers. Around 71% of the total global fresh water withdrawal (3100 billion m^3) is used for agriculture purposes and by 2030, if there are no efficiency gains, it will increase into 4500 billion m^3. The gap between demand and supply can be filled by several types of desalination processes. Desalination is a significant method for producing portable water for human drinking, irrigation and industry (Atab, *et al*., 2018).

The continued deficiency of consumable water is a significant issue in developing countries, and contaminated water can result in various diseases, which are often lethal. According to World Health Organization (WHO) report, about 30,000 people die every day, due to water-borne diseases. As per UNICEF, globally, 1 billion people are currently without access to portable water supply and 2.6 billion have no form of sanitation services. Therefore, purification of available water is essential for the general well-being of the masses. Solar energy can be used as an important source for purifying water for its low manufacturing expenses; and its usage has no adverse impact on the environment. Hence, application of solar stills for distillation of salty water to produce fresh water is economical in terms of energy, but the distillate rate is little low. The solar distillation involves all the three modes: conduction, convection, and radiation of heat transfer. Heat flows from inside the solar still to the environment through the transparent glass cover and the walls by conduction. Heat from the basin to the water, from vapours to the glass cover and from glass cover to the environment is transferred by convection. While heat flows from the sun to the solar still through radiations (Khare, *et al*., 2017).

Solar distillation seems to be a promising method and alternative way for supplying fresh water. Several solar still designs have been proposed and many of them have found significant applications throughout the world. Solar desalination systems have low operating and maintenance costs and require large installation areas and high initial investments. There are two different types of solar stills, those are: active solar still and passive solar still. Active solar still contains the mechanical components like pump, valve, etc. Passive solar still does not require mechanical components. Among active and passive solar stills, passive solar still gets more attractive compared to active solar still, because passive solar still does not have moving elements, so need of power consumption and no wear and tear problems. (Somanchi, *et al*., 2015). In this research, it was used active solar still.

This research aims to study heat transfer in desalination system and the quality of feed water, distilled water and brine compared to the quality standard. Research about sea water desalination in vacuum condition has been conducted before, one of them by Al-Kharabsheh and Goswami (2003). In their research, they used natural method (gravity and atmospheric pressure) to create vacuum condition where water could quickly evaporate at lower temperature and with less energy than conventional techniques. This system consisted of a solar heating system and evaporator that was connected to the condenser at an altitude of about 10 m above the ground surface and was connected through pipe for salt water supply, disposal of concentrated brine and freshwater tank Volume of distilled water produced was 6.5 l/m2.day. Unfortunately, the deficiency of this system is difficulty of achieving a balance of hydrostatic and atmospheric pressure, therefore desalination system to be not vacuumed. The research conducted by Al-Kharabsheh and Goswami (2003) only separated the evaporation and condensation zones, while in this research, the zones of heating, evaporation and condensation are separated. Vacuum condition is made using vacuum pump 418 Watt inside the evaporator in order to fully desalination system under vacuum condition. This is conducted to be able to increase the production of distilled water.

2. RESEARCH METHODOLOGY

This saline water desalination research was conducted at PAU Building 7th floor (outdoor), Institut Teknologi Bandung (ITB). Observation began at 08.00 am and ended at 16.00 pm for six weeks throughout the month of May to August 2013. All measurements were done every once every hour. The measurement consists of measuring environmental conditions that the intensity of solar radiation, wind speed, dry and wet air temperature, and temperature measurements at fourteen points that have been determined. Distillate water production was taken once every hour and the quantity and quality were measured.

Water input at first is stored in water tank, then flowed through the hose to solar collector tank. Solar energy will be absorbed by solar collector to heat water, but some of this energy was lost to environment. After water temperature reached a certain value, water was flowed into

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evaporator. Water flow entering the evaporator arranged with variations: 3.3; 6.5; 12; and 16 mL/sec using a rotameter. Vacuum pump pressure in the evaporator was arranged corresponding with variation of vacuum pressure desired. Variations in vacuum pressure used were -0.05; -0.1; -0.15; -0.2; -0.25; and -0.3 bar. It also conducted tray variations in the evaporator from without tray until five trays. At the bottom of the evaporator will be formed water that are not vaporized (brine). Brine would be streamed back into the water tank. While the vapour will enter into condenser where in condenser, cooling water will be flowed into it so that vapour changed becomes liquid phase. Distilled water product would come out of the bottom of condenser and collected in a container to be analysed its characteristic.

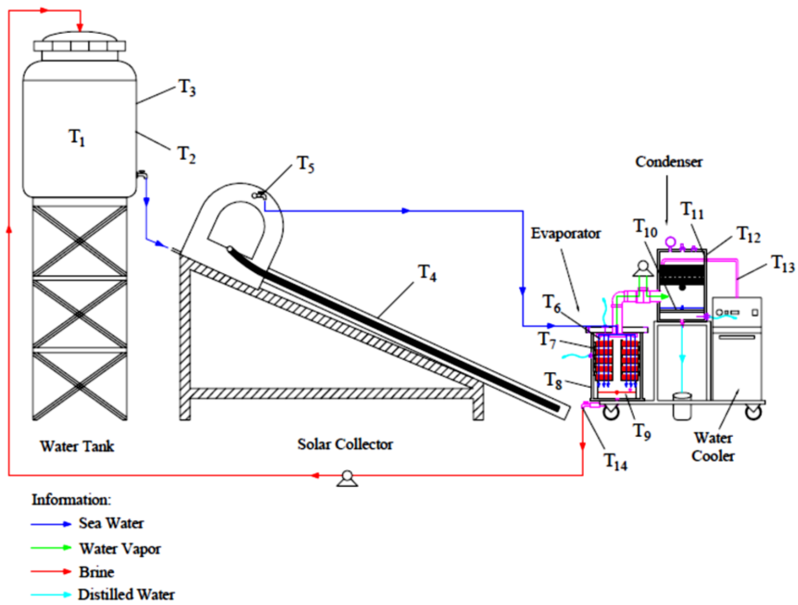

Figure 1 Saline water desalination system

Temperature measurement is needed to observe system performance at the level of production and efficiency. Temperature measurements at fourteen points can be seen in Figure 1. Fourteen temperature measurement points are located attached to the system, namely: T1: water temperature in the water tank (°C); T2: inner wall temperature of the water tank (°C); T3: outer tank temperature of the water tank (°C); T4: surface temperature of solar collector (°C); T5: water temperature from the solar collector to evaporator (°C); T6: vapour temperature in the evaporator (°C); T7: inner wall temperature of the evaporator (°C); T8: outer wall temperature of the evaporator (°C); T9: brine temperature (°C); T10: distilled water temperature (°C); T11: inner

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wall temperature of the condenser (°C); T12: outer wall temperature of the condenser (°C); T13: cooling water temperature (°C); T14: overflow water temperature from the evaporator to water tank (°C).

Quantity of distilled water was measured and recorded every one hour so that it can be analysed the efficiency of saline water desalination equipment in this research. Then after the maximum condition is obtained (seen from vacuum pressure, input water flow, and the number of trays), continued with feed water in the form of saline water with ±38‰ salinity, and then compared its result with feed water ±12‰ salinity. Input water with salinity of 38‰ represents sea water in nature while input water with salinity 12‰ represents brackish water in nature. Brackish water and sea water feed were tested for quality every time the operation of desalination. The quality of distilled water and brine was tested once every hour during the desalination system operation. Samples of sea water that have been taken from the field and distilled water and brine from desalination process would be tested in the laboratory to find out the characteristics. Parameters tested include parameters of drinking water, namely: temperature, pH, salinity, conductivity, turbidity, TDS (Total Dissolved Solid), chloride, ferrous (Fe), hardness, and *Escherichia coli.*

2.1 Data Analysis

Heat transfer in desalination system is calculated using the following equation (Incropera and Dewitt, 2002):

Heat transfer in evaporator and condensor:

$$q_{condition} = \frac{k\,.A}{\Delta x}\ (\Delta\mathrm{T}) \tag{1}$$

Where k is thermal conductivity of insulation material (W/m.K), A is heat transfer surface area, Δx is thick of insulation (m), and ΔT is difference temperature of the inner wall and outer wall system (K).

$$q_{condition} = \mathrm{h}_c\ (\Delta\mathrm{T}) \tag{2}$$

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$$h_{c\ evaporator} = 0.884 \left[T_5 - T_6 \left(\frac{p_5 - p_6}{2016 - p_5}\right) T_5\right]^{1/3} \quad (3)$$

$$h_{c\ condenser} = 0.884 \left[T_6 - T_{13} \left(\frac{p_6 - p_{13}}{2016 - p_6}\right) T_6\right]^{1/3} \quad (4)$$

Where T_5 is water temperature from collector to evaporator (K), T_6 is temperature of water vapor in evaporator (K),), T_{13} is cooling water temperature (K), p_5, p_6, and p_{13} are saturated vapor pressure (mmHg).

$$q_{evaporation-condensation} = h_e(\Delta T) = h_k(\Delta T) \quad (5)$$

$$h_e = \frac{9.15 \times 10^{-7}.h_c.(p_5 - p_6).h_{fg}}{(T_5 - T_6)} \quad (6)$$

$$h_k = \frac{9.15 \times 10^{-7}.h_c.(p_6 - p_{13}).h_{fg}}{(T_6 - T_{13})} \quad (7)$$

Where h_e is evaporative heat transfer coefficient (W/m^2.K), h_{fg} is latent heat of water vaporization (J/kg), and h_c is convective heat transfer coefficient (W/m^2.K), and h_k is condensation heat transfer coefficient (W/m^2.K).

$$q_{radiation} = h_r(T_5 - T_6) \quad (8)$$

$$h_r = F_c \varepsilon_w \sigma\left(T_5^2 + T_6^2\right)(T_5 + T_6) \quad (9)$$

Where h_r is radiative heat transfer coefficient (W/m^2.K), F_c is configuration factor, ε_w is water emissivity, and σ is Stefan Boltzmann constant.

$$(r_2)_{cr} = \frac{k}{h_o} \quad (10)$$

Where $(r_2)_{cr}$ is critical radius when heat transfer rate reaches a maximum (m), k is natural convection heat transfer coefficient (W/m.K), and h_0 is outer convective coefficient (W/m^2.K).

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3. RESULTS AND DISCUSSION

Observation were made from 08.00 - 16.00 for the entire variations in which time-0 shows at 08.00, 1st time shows at 09.00, and so on until the 8th time shows at 16.00.

3.1 Analysis of Heat Transfer in Desalination System

Heat transfer in desalinator involves temperature and heat energy in the system. This relates to temperature measurement at fourteen points (Figure 1). The sections below are the temperatures and heat transfer that occur in the desalinator.

3.1.1 Temperature Profile

Temperature represents kinetic energy of substance molecule (Kanginan, 2002). Temperature profile shows heat distribution process in desalination system. The temperature profile in water tank is shown in Figure 2 for the test conducted on August 15, 2013 with vacuum pressure of -0.3 bar, input water discharge of 5.63 ml/sec, and five trays in the evaporator.

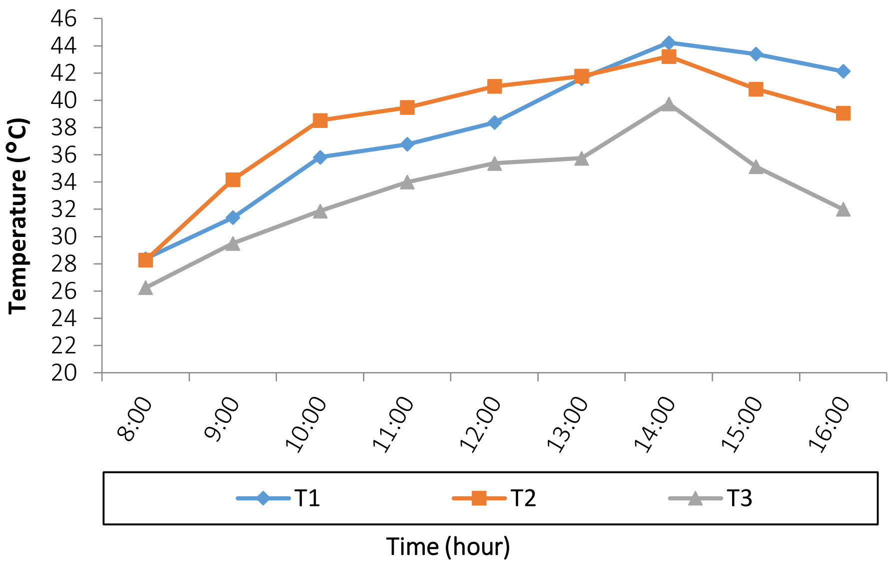

Figure 2 Temperature profile in water tank

T_1, T_2, and T_3 are respectively water temperature in water tank (°C), inner wall temperature of the water tank (°C), and insulation temperature on the outer wall of water tank (°C). From Figure 2 it can be seen that insulation temperature of water tank is lower than water temperature in water tank and inner wall temperature of water tank. The heat in water tank derived from brine water circulated from the evaporator and solar radiation emitted to the water tank. From this picture it is also seen that T_1 in the morning until noon is slightly lower compared to T_2, while in the afternoon towards late afternoon, T_1 increases and exceeds T_2. In the morning until noon, heat in water tank is also affected by high solar radiation, therefore inner wall temperature of the tank will be higher than water temperature. But after noon to late afternoon, solar radiation begins to decrease, hence the heat in the water tank is more affected by brine heat from the evaporator, therefore water temperature in the water tank will be higher than inner wall temperature of the tank. Temperature profile in solar collector is shown in Figure 3 for the test carried out on August 15, 2013, with vacuum pressure of -0.3 bar, input water discharge of 5.63 ml/sec, and five trays in the evaporator.

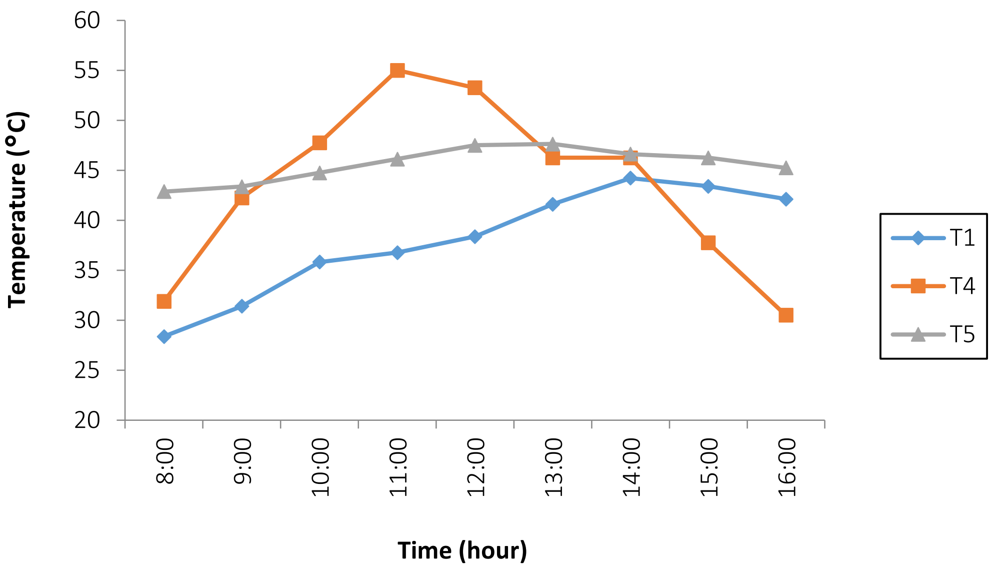

Figure 3 Temperature profile in solar collector

T_1, T_4, and T_5 are respectively water temperature in the water tank (°C), surface temperature of the solar collector (°C), and water temperature from collector to evaporator (°C). From Figure 3 it can be seen that T_4 follows the pattern of solar radiation intensity in one day. T_1 is always lower than T_5, because T_1 is input water temperature before it warms up (an increase in temperature in the solar collector). After input water from water tank is heated in the solar collector, water temperature will rise to a temperature of T_5. This shows that solar collector used has succeeded in increasing input water temperature. Temperature profile in the evaporator is shown in Figure 4 for the test conducted on August 15, 2013, with a vacuum pressure of -0.3 bar, input water discharge of 5.63 mL/sec, and five trays in the evaporator.

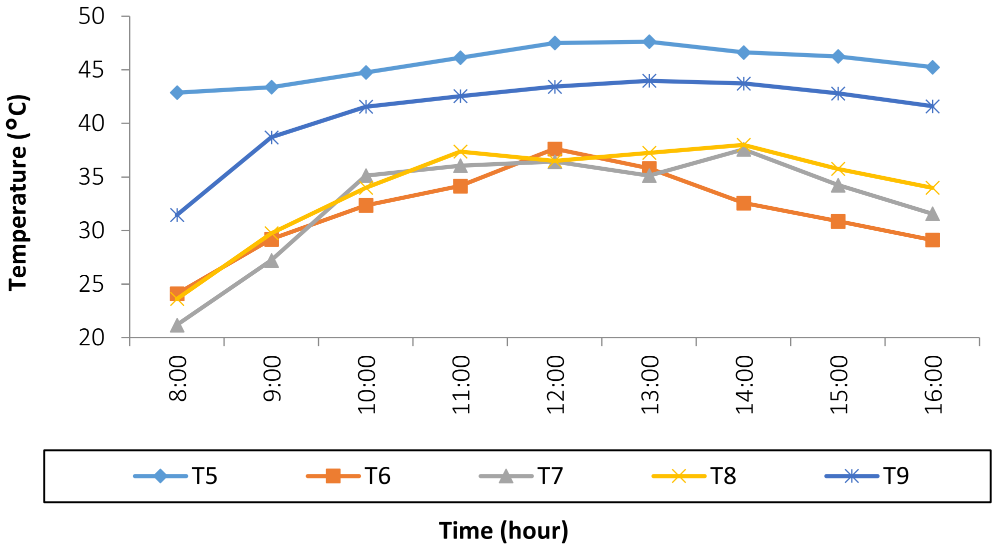

Figure 4 Temperature profile in evaporator

T_5, T_6, T_7, T_8, and T_9 are respectively water temperature from solar collector to evaporator (°C), vapor temperature in the evaporator (°C), inner wall temperature of the evaporator (°C), outer wall temperature of the evaporator and brine temperature (°C). From Figure 4 it can be seen that the highest temperature is T_5, which is input water temperature of the evaporator. The heat in the evaporator comes mostly from input water that enters the evaporator, where some of this flow turns into vapor and some do not evaporate (brine). T_9 (brine temperature) is higher than vapor temperature (T_6) because only a small portion of input water flow becomes vapor. Heat will be brought back from the evaporator to the water tank. Outer wall temperature (T_8) in the evaporator is higher than inner wall temperature (T_7) because in the evaporator there is a process of heat utilization, hence temperature inside the evaporator will be lower. When a liquid evaporates, the particles move very fast. On the surface, some particles can escape into the air, meanwhile others do not have sufficient energy to escape and remain in liquid. When high-energy particles escape, the average energy of the remaining particles is smaller, therefore the liquid cools (Kryukov and Levashov, 2011). That process causes inner wall temperature of the

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evaporator (T_7) to be lower than outer wall temperature of the evaporator (T_8). Temperature profile in the condenser is presented in Figure 5 for the test carried out on August 15, 2013, with a vacuum pressure of -0.3 bar, input water discharge of 5.63 ml/sec, and five trays in the evaporator.

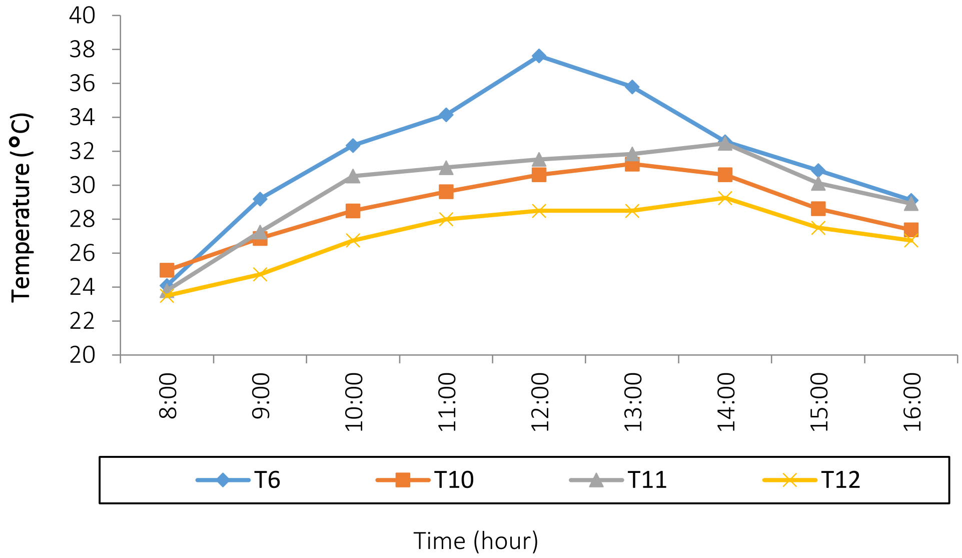

Figure 5 Temperature profile in condenser

T_6, T_{10}, T_{11}, and T_{12} are respectively vapor temperature in the evaporator (°C), distilled water temperature (°C), inner wall temperature of the condenser (°C), and outer wall temperature of the condenser (°C). The heat inside the condenser is mostly derived from vapor entering the condenser (T_6), so that it can be seen from Figure 5, the highest temperature is T_6. Distilled water temperature (T_{10}) is lower than the vapor temperature (T_6) that enters the condenser. Boedisantoso, 2010 stated that if the pollutant gas that is in contact with cooling medium (water or air), then there is a transfer of heat from hot gas to cooling medium, gas vapor temperature will decrease, then kinetic energy of gas molecule will decrease, hence the gas molecules will move close together (van der Waals force) which will cause gas to condense into liquid. Because vapor is in contact with the cooling medium, distilled water temperature (T_{10}) will be lower than vapor temperature (T_6).

From Figure 5 it can also be seen that inner wall temperature of the condenser (T_{11}) is greater than outer wall temperature of the condenser (T_{12}). This is because in the condenser, the energy release process occurs, therefore heat flows from the inner wall towards the outer wall of the condenser.

3.1.2 Heat Transfer in the Water Tank

Heat is a form of energy received by an object that causes the object to change temperature or form. Heat is different from temperature, because temperature is a measure of the degree of heat, meanwhile heat is a quantity or amount of heat, both absorbed and released by an object (Ayanur, 2012). Heat transfer occurs in each desalination unit, which is located in the water tank, solar collector, evaporator, and condenser. Therefore heat transfer in each desalination unit needs to be analyzed. Heat transfer by conduction-convection from water tank to the environment is presented in Figure 6.

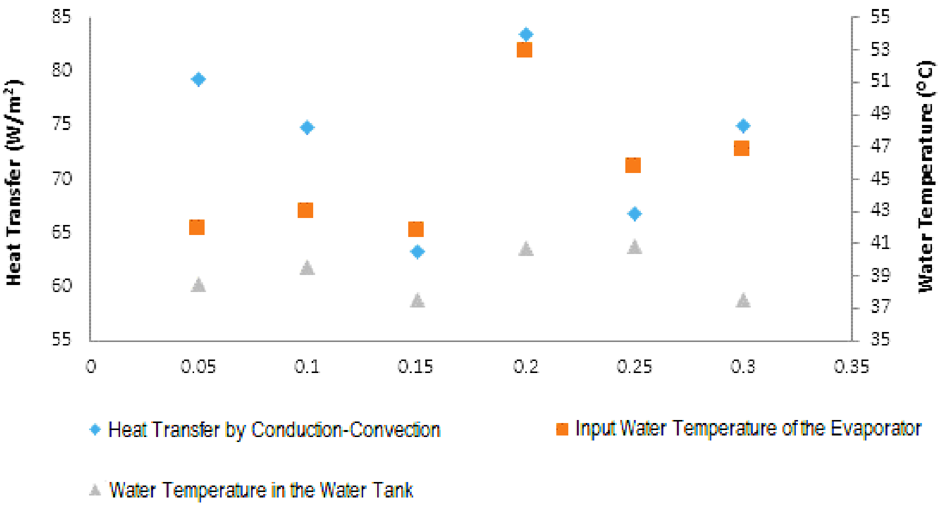

Figure 6 Heat transfer in the water tank

The outside of the water tank in this research is coated with insulation in the form of harmaflex with a thickness of $^3/_8$ inches. Geankoplis (2003) stated that on the outer surface of insulation exposed to the environment there will be heat transfer by convection. The cylinder has high thermal conductivity and the inner temperature of T_1 at point r_1 on the outside of the cylinder is fixed (Figure 7). Heat transfer from water tank to the environment for vacuum pressure -0.05; -0,1; -0.15; -0.2; -0.25; and -0.3 bar respectively are 79.24; 74.86; 63.26; 83,52; 66.83; 75.04 W/m^2. Figure 6 shows that the largest heat transfer from water tank to the environment occurs at a vacuum pressure of -0.2 bar. This is due to the pressure, the temperature of water entering the evaporator is highest among other water temperatures, which is 52.89 °C. The higher the temperature of the water from the collector to the evaporator, the higher the temperature of brine recirculate from the evaporator to the water tank, therefore water temperature in the water tank is also higher. This causes the temperature difference between the water tank and the environment to increase, hence the greater the heat transfer from the water tank to the environment.

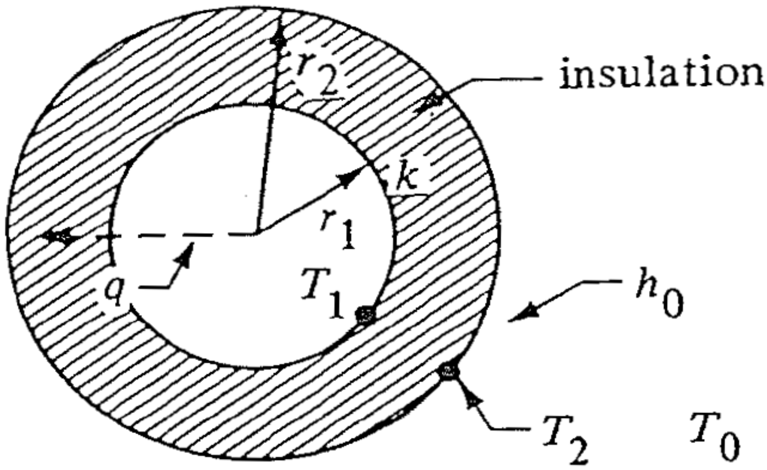

Figure 7 Cylinder with insulation

Geankoplis (2003) stated that to determine the effect of insulation thickness on heat transfer (q), the critical radius value must be calculated when the heat transfer rate is maximum. The critical radius of the water tank is calculated by referring to Equation 10. Calculation of the critical radius of the water tank is presented in Table 1.

Table 1 Critical radius of the water tank at various vacuum pressure

No.	Vacuum Pressure (minus bar)	The Outer Radius of The Tank (m)	Critical Radius (m)
1.	0.05	0.299525	0.00804
2.	0.10		0.00820
3.	0.15		0.00840
4.	0.20		0.00842
5.	0.25		0.00833
6.	0.30		0.00827

Geankoplis (2003) stated that if the outer radius r_2 is less than the critical value, adding more insulation will actually increase the heat transfer rate q. But if the outside is bigger than critical, adding more insulation will reduce the rate of heat transfer. From Table 1 it can be seen that the outer radius of the tank (r_2) is greater than the critical radius. This describes that adding more insulation will reduce the rate of heat transfer from the water tank to the environment, so heat loss can be reduced. The insulation material used in this research is in the form of Harmaflex sheets with a thickness of $^3/_8$ inches. From this explanation it can be concluded that the addition of a larger Harmaflex thickness will reduce the rate of heat transfer from the water tank to the environment.

3.1.3 Heat Transfer in the Evaporator

Conduction is heat transfer process without particle displacement, convection is a heat transfer that is accompanied by movement particle matters, while radiation is the transfer of heat energy in the form of electromagnetic waves (Incropera, 2002). This heat transfer will affect evaporation process in the evaporator and condensation process in the condenser.

Heat conduction is not significantly affecting the evaporation process, since this heat transfer is very small. Evaporative heat transfer is dominant heat transfer in the evaporator because in the evaporator occurs evaporation process where molecules collect enough energy to escape the liquid phase and enter the room on the liquid-gas interface. Evaporative heat transfer for vacuum pressure -0.05; -0.1; -0.15; -0.2; -0.25; and -0.3 bar was 173.77; 180.07; 190.79; 481.66; 242.57; and 359.18 W/m^2 respectively. From Figure 8 it can be seen that input water temperature is directly proportional to the evaporative, convective, and radiation heat transfer. This indicates

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that the higher the water temperature the greater the difference temperature between water temperature and vapor temperature, hence the greater the heat transfer occurs in the evaporator. Heat will affect the rate of evaporation. Hot fluid molecules vibrate faster and with more energy than cold fluid. The addition of thermal energy can make molecules easier to escape from liquid (Kryukov and Levashov, 2011). The higher the temperature of a liquid, the faster the movement of molecules in the molecular collision will occur which will cause the faster process of mass transfer from liquid to gas (Olujic, 2013).

Since input water temperature of the evaporator varies for each variation of vacuum pressure, the effect of vacuum pressure on heat transfer in the evaporator cannot be clearly seen. But from Figure 8 it can be seen the tendency that occurs, namely the greater the vacuum pressure (the lower the pressure in space), the heat transfer that occurs is increasing. The lower the pressure in chamber (the higher the degree of vacuum) then the higher heat transfer occured. The higher the degree of vacuum will give the lower the density of fluid in space, which means the movement of fluid is faster. It is also related to Nusselt number (a function of heat transfer coefficient). The lower the density of fluid, Nusselt number will increase, which means convection current is higher (Mulyono, 2008).

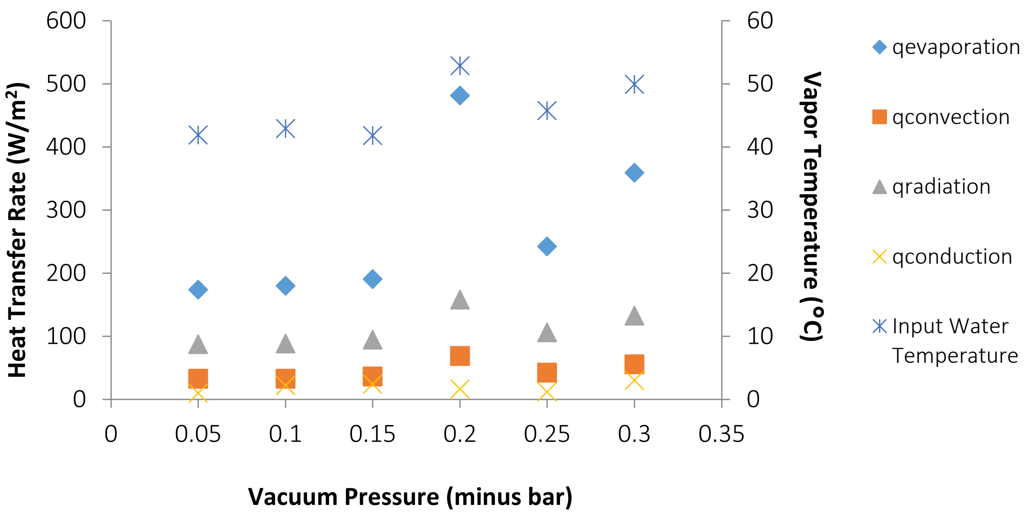

Figure 8 Heat transfer in the evaporator

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3.1.4 Heat Transfer in the Condenser

Heat transfer also occurs in the condenser where in the condenser there is a phase change from vapor to liquid. Heat transfer by condensation is the most dominant heat transfer in the condenser because in the condenser there is a condensation process where the heat energy is released from gas to the cooling medium and kinetic energy of vapor molecule will decrease, therefore vapor molecules move close together which will cause vapor condense into liquid (Kryukov and Levashov, 2011). Heat transfer by condensation, convection, and conduction in each condenser is calculated by referring to Equations (5), (2), and (1). Heat transfer inside the condenser is presented in Figure 9.

Condensation heat transfer for vacuum pressure -0.05; -0.1; -0.15; -0.2; -0.25; and -0.3 bar was 143.32; 152.90; 122.25; 155.64; 161.99; and 164 W/m^2 respectively. From Figure 9, it can be seen that the highest heat transfer occured at vacuum pressure of -0.3 bar. This described that the highest amount of vapor that condensed in the condenser occured at -0.3 bar vacuum pressure. In the condenser, occured the release of heat energy from to cooling medium in which the kinetic energy of vapor molecules will be reduced so that vapor molecules move closer together (Van der Waals Force) which will cause vapor was condensed into liquid (Kryukov and Levashov, 2011).

The boiling point of liquid at vacuum pressure of -0.3 bar is lowest compared to other vacuum pressures so that the amount of vapor per input energy produced will be greater and more condensed inside the condenser. In addition, vapor temperature at vacuum pressure is -0.3 bar, the highest compared to other vacuum pressures, which is 31.25 °C. The higher the vapor temperature, the greater the temperature difference between the temperature of vapor and the temperature of the cooling water, hence more heat energy is released and distilled water per input energy produced will increase. Boedisantoso (2010) stated that if hot pollutant gases come into contact with cooling media, then heat transfer from gas to the cooling medium occurs. Therefore, with the higher the vapor temperature, the greater the heat transfer that occurs from gas to the cooling medium.

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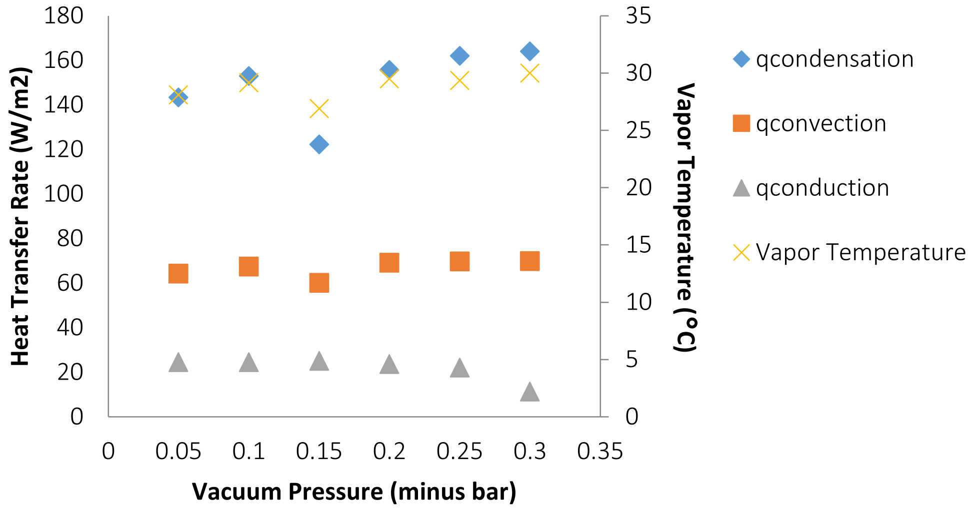

Figure 9 Heat transfer in the condenser

3.2 Water Quality Analysis

Water quality analysis in this research consists of analysis of feed water, distilled water, and brine quality. The quality of distilled water and brine was tested once every hour during the desalination system operation. Parameters tested include parameters of drinking water that are temperature, pH, salinity, conductivity, turbidity, Total Dissolved Solid (TDS), chloride, ferrous (Fe), hardness, CO_2 aggressive, and *E. coli*.

3.2.1 Feed Water Quality

The salt content dissolved in feed water will determine the efficiency of the desalinator. To determine the quality of feed water to be trated, the quality of feed water was measured for eight hours of observation as shown in Table 2. Measurement of artificial brackish water quality was carried out by averaging the data taken on May 27, June 1, and June 10, 2013 meanwhile artificial sea water quality measurement was carried out on August 24, 2013.

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Table 2 Comparison of feed water quality for eight hours observation in water tank

Time	Conductivity (µS/cm)		TDS (mg/L)		Salinity (‰)	
	Artificial Brackish Water	Artificial Sea Water	Artificial Brackish Water	Artificial Sea Water	Artificial Brackish Water	Artificial Sea Water
08.00	21,100	56,000	10,560	28,000	12.63	38
09.00	21,567	56,400	10,780	28,200	12.90	38.1
10.00	21,767	56,400	10,877	28,200	13.00	38.2
11.00	21,833	56,500	10,920	28,250	13.06	38.2
12.00	21,867	56,700	10,927	28,350	13.08	38.2
13.00	21,867	56,900	10,940	28,450	13.09	38.5
14.00	21,900	57,300	10,957	28,650	13.12	38.6
15.00	22,100	58,000	11,040	29,000	13.22	38.9
16.00	22,167	58,900	11,097	29,450	13.35	39.4

From Table 2 it can be seen that there is an increase in conductivity, Total Dissolved Solid (TDS), and salinity in feed water for each hour even though the increase is not significant. The increase is because the recirculation of brine that does not evaporate from evaporator to water tank. Al-Kharabsheh and Goswami, 2003 stated that evaporation from saltwater increases salinity of feed water itself, which tends to reduce the evaporation rate and increase the likelihood of scale formation. So it is necessary to draw brine concentrated at a certain flow rate and inject saltwater at a rate equivalent to the amount of withdrawal and evaporation rate.

From Table 2 it can also be seen that the values of conductivity, Total Dissolved Solid (TDS), and salinity of artificial sea water are higher than artificial brackish water. This describe that the content of dissolved salt in artificial sea water is higher that artificial brackish water, therefore the density and molarity of artificial sea water is higher than artificial brackish water.

3.2.2 Characteristic of Feed Water and Brine

Feed water used in this research is artificial brackish water (12 ‰ salinity) and artificial sea water (38 ‰). Both types of feed water have different characteristics. The quality of feed water used and brine left over from the desalination process in this research are shown in Table 3.

Table 3 Feed water and brine quality

Parameter	Unit	Artificial Brackish Water	Brine	Artificial Sea Water	Brine	Quality Standard*
Temperature	°C	24 - 31	29.5-37	24.2 - 42.5	34.9-45.3	-
pH	-	6.88-8.44	7.54-8.41	8.79	-	6.5 - 8.5
Salinity	‰	10.5-15.34	11.75-14.69	38.0-39.4	37.1-39.3	-
Conductivity	µS/cm	17,820-25,200	19,800-24,200	56,000-58,900	55,100-57,500	-
Turbidity	NTU	10.5-50.1	4.6-90.3	42.3	-	5
Total Dissolved Solid (TDS)	mg/L	9,860-12,600	9,900-12,110	28,000-29,450	27,550-28,750	500
Chloride	mg/L	7,019-8,062.39	-	18,088	-	250
Ferrous (Fe)	mg/L	2.34	-	4.33	-	0.3
Ca Hardness	mg/L	20.20	-	27.88	-	-
Mg Hardness	mg/L	10.45	-	7.61	-	-
Total Hardness	mg/L	30.65	-	35.49	-	500
CO_2 aggressive	mg/L	39	-	41	-	-
E.coli	count/100 mL	11	-	12	-	0

**Quality standard refers to Minister of Health Regulation No. 492/2010*

Based on the water acidity level classification presented by Safitri (2011), artificial brackish water and artificial sea water used in this research are included in the saltwater category, because TDS content in water is in the range of 10,000-35,000 mg/L. However, seen from the percentage of dissolved salt as described by Romimohtarto and Juwana (2007), artificial brackish water is included in the category of brackish water because it contains salinity in the range of 0.05-3%, meanwhile artificial seawater is included in saline water category because it contains salinity in range 3-5%.

Brine from residual artificial brackish water and artificial sea water processing is still classified as saltwater based on TDS parameter, because it contains TDS in the range of 10,000-35,000 mg/L. In terms of salinity parameter, brine from artificial brackish water processing is classified as brackish water while brine from artificial sea water treatment is classified as saline water. It can be concluded that brine produced from this research is not included in the brine category because it contains TDS which is less than 35,000 mg/L and salinity less than 5%. The

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concentration of salt water (brine) is usually found to be double or close to twice that of natural sea water. Salt returned to the sea is identical to that in feed water, but water is now at a higher concentration (Astuti, 2005). But brine produced from this research is almost the same as feed water that is given even sometimes lower. This can be caused by the recirculation of brine from the evaporator to the water tank where brine is not collected in a container, but is being recirculated back into the desalination system for reprocessing. Astuti (2005) mentioned some characteristics of the disposal of salt water concentrates from desalination units, including:

1. Throw it directly into the sea.
2. Combine with other wastes before being discharged into the sea.
3. Throw it into the drainage channel for processing in the wastewater treatment unit.
4. Drying the salt water concentrate which is then discharged to landfill.

Biological parameter tested in this research is *E.coli*, a type of fecal coliform bacteria that is usually found in the intestines of animals and humans. *E. coli* bacteria in water that is derived from contamination of animal and human feces which cause various kinds of diseases (Said, 2007). The high *E. coli* content in feed water in this research can be caused by unsterile containers and the manufacture of feed water from tap water.

Safitri (2011) stated that two properties that are affected by the amount of salt in the sea (salinity) are electrical conductivity and osmosis pressure. In this research it can be seen that the conductivity in feed water is quite high, that are 17,820-25,200 mg/L for artificial brackish water and 56,000-58,900 mg/L for artificial seawater, so it can be said that the salt content of feed water is quite large. In addition Safitri (2011) stated sea water is a mixture of 96.5% pure water and 3.5% other materials such as salts, dissolved gases, organic materials, and non-particles dissolved. The main salts contained in seawater are chloride (55%), sodium (31%), sulfate (8%), magnesium (4%), calcium (1%), potassium (1%), and the rest consisting of bicarbonate, bromide, boric acid, strontium and fluoride. It can be seen from Table 3 that the chloride content in feed water is very high, which is in the range 7019-8062.39 mg/l for artificial brackish water and 18,088 mg/L for artificial seawater.

3.3 Distilled Water Quality

Artificial brackish water and artificial sea water have different characteristics, therefore it is

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necessary to analyze the quality of distilled water produced from both types of feed water. The quality of distilled water produced from artificial brackish water and artificial sea water is presented in Table 4. From Table 4, it can be seen that the quality of distilled water product met drinking water quality standard based on the Minister of Health Regulation No. 492/2010 for parameters: temperature, pH, salinity, conductivity, turbidity, chloride, TDS, ferrous, and hardness except for *E.coli* parameter do not met quality standard. This is because the distillation process is a physical process where processing is based on differences in the boiling point of liquid so that it cannot set aside biological parameters. In addition, the presence of *E.coli* in distilled water can also because unsterilized reactor conditions and contact with hands or objects that have been contaminated.

Assomadi (2008) stated that desalination by the distillation process will produce fresh water which is very high in purity. This can be seen from the salt content in distilled water produced from this desalination system is very low. It is proven by the parameters of salinity, conductivity, TDS, and chloride that are far below the drinking water quality standard. In addition, Safitri (2011) stated that the distillation process produces high quality water with TDS (Total Dissolved Solid) values in the range between 1.0 - 50 ppm. From the results of this research, it was obtained that the content of TDS in distilled water was 10.75 - 250 mg/L for artificial brackish water and 15.3 - 27.45 mg/L for artificial sea water. The content of TDS in this distillate water in some observations reaches more than 50 ppm, but still meets the drinking water quality standards. This can be caused by the condition of the reactor which is less clean, hence there is a high TDS content of feed water in the evaporator into the condenser and affecting the distillate water formed in the condenser.

Reduction of salt content in saline water occurred significantly. It can be seen from the parameter of conductivity, chloride, and TDS. From these results it can be said that the sea water desalination system proposed in this research deserve to be applied as a seawater treatment plant.

Table 4 Water quality in desalination process

Parameter	Unit	Artificial Brackish Water	Distilled Water	Artificial Sea Water	Distilled Water	Quality Standard*
Temperature	°C	24 - 31	27 - 30	24.2 - 42.5	23.7 - 31.6	-
pH	-	6.88 - 8.44	6.6 - 7.62	8.79	-	6.5 - 8.5
Salinity	‰	10.5 - 15.34	0.02 - 0.24	38.0 - 39.4	0.02 - 0.09	-
Conductivity	µS/cm	17,820 – 25,200	21.5 - 500	56,000 – 58,900	30.6 - 54.9	-
Turbidity	NTU	10.5 - 50.1	1.26 - 8.21	42.3	-	5
Chloride	mg/L	7,019	70.54 - 93.02	-	-	250
TDS	mg/L	9,860 – 12,600	10.75 - 250	28,000 – 29,450	15.3 - 27.45	500
Ferrous (Fe)	mg/L	2.34	0.0045 - 0.0049	-	-	0.3
Ca Hardness	mg/L	20.20	0.153 - 0.175	-	-	-
Mg Hardness	mg/L	10.45	0.0012 - 0.0019	-	-	-
Total Hardness	mg/L	30.65	0.1542 - 0.1769	-	-	500
E. coli	cell/100 mL	11	11	-	-	0

** Quality standard refers to Minister of Health Regulation No. 492/2010*

4. CONCLUSION

Heat transfer in desalination system occurs by conduction, convection, radiation, and evaporation-condensation. From the result of observation, it was found that evaporative heat transfer for vacuum pressure -0.05, -0.1, -0.15, -0.2, -0.25, and -0.3 bar respectively were 173.77, 180.07, 190.79, 481.66, 242.57, and 246.24 W/m^2. The result of water quality test of distilled water produced from saline water desalination for some parameters respectively were pH 7.4; turbidity 2.73 NTU; TDS 27.45 mg/L; chloride 84.98 mg/L; Fe 2.13 mg/L; total hardness 0.1698 mg/L; and *E.coli* 12 cell/mL. From distilled water quality test, it obtained that distilled water produced has met drinking water quality standard based on the Minister of Health Regulation No. 492/2010 for parameters: temperature, pH, salinity, conductivity, turbidity, chloride, TDS, ferrous, and hardness, except for *E.coli*. These results indicate that the proposed desalination system feasible to be applied as a seawater treatment plant.

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